

## **Develop and apply methods for assessing fire safety in nuclear facilities**

### **RES/DRA**

The development of risk-informed, performance-based fire standards and regulations requires a sound understanding of fire phenomena and its contribution to overall nuclear power plant (NPP) risk. A fire research program has been developed and is being implemented to provide realistic solutions to complex issues associated with Fire Probabilistic Risk Assessment (PRA) and fire modeling to support risk-informed changes to these standards and regulations. The Office of Nuclear Regulatory Research (RES) is also performing specialized testing to support other NRC program offices.

The staff worked with the National Fire Protection Association (NFPA) to develop a performance-based, risk-informed fire protection standard (NFPA 805) for NPPs. NFPA 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," was issued in January 2001 and serves as the basis for the rule, 10 CFR 50.48(c). The NRC-RES and Electric Power Research Institute (EPRI) under a Memorandum of Understanding (MOU) have provided much of the technical basis for this implementation by developing tools critical to performing fire PRA and fire modeling. RES is conducting these activities at the request of a formal Office of Nuclear Reactor Regulation (NRR) User Need request.

In order to address the need for qualified fire PRA practitioners, RES and EPRI annually conduct two detailed, hands-on fire PRA training courses. This training is based upon the jointly developed document, NUREG/CR-6850 (EPRI 1011989) "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," and corresponds directly to the offered training courses. RES and EPRI provide training in five subject areas related to fire PRA: (1) fire analysis, (2) PRA, (3) human reliability analysis (HRA), (4) electrical analysis, and (5) advanced fire modeling. Participants select one of these subject areas and spent the duration of the course in the technical module that covered their chosen subject area. The training incorporates state-of-the-art fire PRA enhancements: for example, the HRA module covered guidance provided in NUREG-1921 (EPRI 1023001), "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," and the advanced fire modeling module covered the fire modeling guidance provided in NUREG-1934 (EPRI 1019195), "Nuclear Power Plant Fire Modeling Application Guide." For each technical area, the workshops also include a one-day module introducing the fundamentals of the subject, to assist students without an extensive background in the technical areas in understanding the in-depth training modules that follow. Attending the fundamentals modules is optional. The workshop's format allows for in-depth presentations and practical examples directed towards the participants' areas of interest.

Approximately 190 representatives attended the training in 2012, including NRC employees from RES, the Office of Nuclear Reactor Regulation, the Office of New Reactors, and the NRC's four regional offices, licensees, consultants, other federal agencies (Alcohol Tobacco & Firearms, Ohio 8th District Court of Appeals, the National Institute of Standards and Technology, Defense Nuclear Facilities Safety Board and the Naval Surface Warfare Center), and representatives from outside the United States (Belgium, Canada, South Korea, Spain and Taiwan). RES and EPRI had previously conducted more general fire PRA workshops in 2005 and 2006, with the detailed training being developed at the request of both internal and external stakeholders who attended the joint workshops.

RES began a joint project in early 2008 with EPRI and National Institute of Standards and Technology (NIST) to provide guidance to users of mathematical fire modeling computer codes for NPP applications. This guidance will help ensure consistent and realistic application of fire modeling tools used in fire PRAs for NFPA 805 license transitions and other licensing and inspection actions. Draft NUREG-1934 (EPRI 1023259), NPP Fire Modeling Application Guide, was submitted for peer review in August 2009 and was issued for public comment in early 2010. Based on the large number of public comments, the report was revised and issued for a second public comment period in August 2011. The draft report is also being used as “textbook” for the Advanced Fire Modeling course being taught as part of the 2011 and 2012 joint NRC/EPRI NUREG/CR-6850 training. Comments developed from the classroom sessions and the public will be used to revise the document as necessary. The final document is scheduled for release in late 2012.

RES is working jointly with EPRI to develop detailed guidance for performing quantitative human reliability analysis (HRA) for post-fire mitigative human actions modeled in a fire PRA. This guidance builds upon the existing information in NUREG/CR-6850 (EPRI 1011989) and takes into account the ASME/ANS PRA Standard (RA-Sa-2009). NUREG-1921 (EPRI 1019196) EPRI/NRC-RES Fire Human Reliability Analysis Guidelines was released for public comment in December of 2009. The NUREG was published as a final report in July 2012. A module in fire HRA was added to the 2010 NRC-RES/EPRI Fire PRA workshop to provide training on this methodology, and was conducted in the August 2011 and 2012 training.

RES is supporting the NRR Circuit Analysis Resolution Program. RES previously performed the testing and provided the technical basis for RIS 2004-03 Bin 2 items. This RIS identified circuit issues to be inspected and other lower risk issues that possibly should be subjected to inspection but which needed additional tests and analyses for final determination. RES provided these additional tests and analyses with the “Cable Response to Live Fire” (CAROL-FIRE) program, which was started in CY 2006 and published as the three-volume NUREG/CR-6931 in April, 2008.

RES continues to provide support to the NRR Circuit Analysis Resolution Program by conducting direct current (DC) circuit testing in collaboration with EPRI. This testing began in July 2009 and the report, “Direct Current Electrical Shorting in Response to Exposure Fire” (DESIREE-Fire) (NUREG/CR-7100), was published in April 2012. This testing program was requested by NRR based on the results of the limited number of DC circuit tests performed by Duke Energy in 2006. This testing indicated there is a potential for DC circuits to respond differently than alternating current (AC) circuits to the hot short phenomenon as previously thought. Several DC circuits in NPPs are of high risk significance and their unintended spurious operation resulting from fire damaged cable may have a significant impact on the plants’ ability of achieving post-fire safe shutdown conditions. The principle purpose of this project was to determine the risk significance of DC circuits by conducting appropriate fire tests. The testing will provide a comparison of DC circuit failure likelihood relative to that of the AC circuits previously tested.

New, more realistic probability values relevant to circuit analyses will be developed from these AC and DC testing and analysis programs. These values are being developed through the application of a Phenomena Identification and Ranking Table (PIRT) and Expert Elicitation process. The PIRT panel report, “Joint Assessment of Cable Damage and Quantification Effects from Fire” (JACQUE-FIRE) Volume 1, is expected to be published in late 2012. The PIRT process also led to the publication of the “Electrical Cable Test Results and Analysis During Fire

Exposure” (ELECTRA-FIRE) (NUREG-2128). This supported the electrical expert PIRT panel, allowing members to make informed decisions and consisted of a consolidation of the three major fire induced circuit and cable failure experiments. Volume 2 of the JACQUE\_FIRE report will incorporate lessons learned through the PIRT panel publications using an Expert Elicitation process. The objective of this project is to provide best estimate conditional probabilities on the likelihood of hot short-induced spurious operation given fire-induced cable damage for use in Fire PRA applications. These conditional probabilities will revise, directly replace, or create new probabilities for values currently reported in NUREG/CR-6850 (EPRI 1011989). These advancements will be incorporated into the Fire PRA process, helping to reduce the uncertainty of predicting cable failure in fire PRA applications.

In addition to the continued support for the NRR Circuit Analysis Resolution Program RES has also published the “Cable Heat Release, Ignition, and Spread in Tray Installations During Fire” (CHRISTI-FIRE) (NUREG – 7010) Volume 1 in July 2012. CHRISTIFIRE Volume 1 addresses the burning behavior of a cable in a fire beyond the point of electrical failure in horizontal cable trays. The data obtained from this project can be used for the development of fire models to calculate the HRR and flame spread of a cable fire. The experiments conducted range from bench-scale measurements of the effluent from small samples of burning cables to full-scale measurements of the HRR and spread rate of cables burning within typical ladder-back, open cable trays. Phase II of this program will focus on Hallways and Vertical Shafts and is expected to be published in early 2013.

In 2010, RES completed an aspect of its support to NRR by assisting in the provision of interim solutions to the existing fire PRA questions in the NFPA 805 frequently asked questions (FAQ) program. EPRI supported RES in this endeavor since it participated in the development of these realistic solutions, given on our available knowledge, by proposing their own solutions and reviewing RES solutions. Fifteen fire PRA questions were posed by industry, and spanned many different aspects of fire PRA. All fire PRA FAQs to date were successfully resolved with new research arising from some of those technical questions. These fire PRA FAQ solutions were consolidated in NUREG/CR-6850 Supplement 1 (EPRI 1019259), which was published in September 2010. Ongoing research will continue as updates become available to NUREG/CR-6850. These updates will be captured in a modular format to be agreed upon with EPRI cooperation.

RES also supported NRR by participating in the staff audit of the fire PRAs performed by the two pilot plants transitioning to 10 CFR 50.48(c). In these audits, the staff evaluated the conformance of pilots’ fire PRAs to the fire portion of the ASME/ANS PRA Standard. RES has also provided support to NRR by attending earlier observation visits to these two pilot plants, by reviewing technical materials for those plants’ transition, and by supporting the resolution to fire PRA frequently-asked-questions (FAQs) program. RES’ role in these visits and reviews is to ensure that its technical documents are implemented properly, as well as to collect insights relevant to these technologies. RES continues to support the ongoing FAQ program.

RES issued Revision 2 of R.G. 1.200 in March of 2009. This regulatory guide documented the staff’s position on the fire PRA portion of the ASME/ANS PRA Standard and on the NEI Fire PRA Peer Review Guidance. The ASME/ANS PRA standard is a part of the Commission’s phased approach to PRA quality (SECY-04-0118), and will support implementation of the risk-informed, performance-based rule endorsing NFPA 805. The fire PRA Standard was originally developed under the auspices of the American Nuclear Society (ANS), but was integrated into the combined ASME/ANS PRA standard. Previously, RES provided substantial support to the Committee for drafting and reviewing the Standard.

RES in collaboration with National Institute of Standards and Technology issued A Literature Review of Effects of Smoke from a Fire on Electrical Equipment (NUREG – 7123) in July 2012. This report investigates state of the art knowledge of smoke production measurement, prediction of smoke impact as part of computer-based fire modeling, and measurement and prediction of the impact of smoke through deposition of soot on and corrosion of electrical equipment. The overall objective of this research program is to develop a better understanding of how fire induced smoke production and transport can affect electronic equipment that may be used in an NPP. This report presents a review of the measurement of the impact of smoke through deposition of soot on and corrosion of electrical equipment, smoke production measurement, and prediction of smoke impact as part of computer-based fire modeling.

RES in collaboration with EPRI has also initiated an update to the EPRI fire events database which was used in the development of NUREG/CR-6850. Data for fires occurring from 2001 to 2009 are being added to the database, and more current, realistic fire ignition frequencies established as identified in a fire NFPA 805 PRA frequently-asked-question (FAQ). RES and EPRI have planned for a joint report in CY2012 on this project. Furthermore, RES is evaluating fire protection metrics on 10CFR50.72/73 reportable fires and on fire protection findings, and continues to issue reports on an annual basis to account for new events and findings. Working with EPRI under the current memorandum of understanding (MOU) RES will be expanding this evaluation to include information regarding trending of long term compensatory measures.

As a part of its “knowledge management” activities, RES has issued several brochures such as the history of NRC’s fire safety research (NUREG/BR-0364), a brochure that compiles facts and analyses related to the 1975 fire at the Browns Ferry Nuclear (BFN) Power Plant (NUREG/BR-0361), and more recently the publication of the Three Mile Island Accident of 1979 Knowledge Management (KM) Digest (NUREG/KM-0001). The BFN brochure preserves the history and impact of the BFN fire on fire regulations to educate future generations of fire safety professionals. NUREG/BR-0364 shares over 30 years of regulatory and scientific knowledge with our inspectors, licensees, reviewers, and other interested stakeholders, including fire related documents such as NUREGs, inspection procedures, generic letters, and information notices. Revisions for NUREG/BR-0361 and NUREG/BR-0364 are to be completed by early CY2013. The TMI KM Digest is a collection of historical documents and presentations related to the accident at TMI. The NUREG/KM is a new initiative from RES to develop a category of NUREG dedicated to Knowledge Management.

RES published NUREG-1924 in May 2010, which documents the history, issues and regulatory footprint and site specific use of electric raceway fire barrier systems (ERFBS) used in NPPs. The reports consolidates documentation regarding all known raceway fire barrier systems including their effectiveness, information regarding the fire endurance testing of the systems, and how the NRC achieved closure for any related open issues. NUREG-1924 is a complement to the GAO report issued in June 2008 titled, “Nuclear Safety – NRC’s Oversight of Fire Protection at U.S. Commercial Nuclear Reactor Units Could Be Strengthened, GAO-08-0747.”

In December 2011, RES published the Draft for Public Comment of NUREG/CR-7114 “Methodology for Low Power/Shutdown Fire PRA”. RES received comments in April 2012 and met with industry on October 2012 to discuss how NRC was to address their comments and future steps. NUREG/CR-7114 documents current gaps and a framework for conducting Low Power and Shutdown Fire PRA. The framework presented is an extension of the at-power fire PRA methodology jointly developed by EPRI and NRC-RES.

RES supported the Office of Nuclear Materials Safety and Safeguards (NMSS) in several PRA and risk-informed studies related to Fuel Cycle Facilities and Transportation applications.

These areas include:

- Insights from analyses of events and inspection reports to support the development of Significant Determination Process Tools for the Fuel Cycle Oversight Process (Completed in December 2011).
- Spent fuel cask seal performance testing of transportation packages in beyond-design-basis fires to assess the possibility of environmental release of radioactive materials (the first phase was completed in April 2012 with the publication of NUREG/CR-7115 and the second phase of testing started in October 2012 and would include further characterization of Polymeric Seals and Double O-Ring configurations).

Future work being planned includes risk assessment of cable fires and spurious operations in FCF and continued support to Fuel Cycle Oversight Process SDP Tools Development.

| Selected Major Milestones and Schedules  |                      |               |                 |                    |
|--|----------------------|---------------|-----------------|--------------------|
| Major Milestones   | Original Target Date | Revised Date  | Completion Date | NRC Responsibility |
| Publish report on fire risk requantification, NUREG/CR-6850  | September 2005       |               | September 2005  | RES/DRASP          |
| Issue Final fire model verification and validation report NUREG-1824   | January 2007         |               | May 2007        | RES/DRASP          |
| Publish final CAROLFIRE NUREG/CR reports   | March 2008           | April 2008    | April 2008      | RES/DRA            |
| Issue fire model users guide   | February 2009        | December 2012 |                 | RES/DRA            |
| Issue fire portion of R.G. 1.200, rev 2.   | March 2009           |               | March 2009      | RES/DRA            |
| Risk Assessment of Red Oil Explosions in the Mixed Oxide Fuel Fabrication Facility   | August 2009          |               | August 2009     | RES/DRA            |
| Issue final NUREG/CR on DC circuit testing results   | June 2010            | December 2011 | April 2012      | RES/DRA            |
| Publish NUREG/CR-6850 Supplement 1 on Fire PRA FAQs  | September 2010       |               | September 2010  | RES/DRA            |
| Incorporate CAROLFIRE and DC circuit results into Fire PRA process (culmination of results from ELECTRA-FIRE & JACQUE-FIRE Volume 1 / Volume 2)  | December 2010        | July 2013     |                 | RES/DRA            |
| Publish Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE), A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011 (NUREG-2128) | June 2012            |               | June 2012       |                    |
| Publish JACQUE FIRE report Volume 1- PIRT  | August 2012          | November 2012 |                 | RES/DRA            |
| Publish JACQUE FIRE report Volume 2- Expert Elicitation  | July 2013            |               |                 | RES/DRA            |
| Publish A Literature Review of Effects of Smoke from a Fire on Electrical Equipment (NUREG – 7123)   | July 2012            |               | July 2012       | RES/DRA            |

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| Publish Cable Heat Release, Ignition, and Spread in Tray Installations during fire. (CHRISTI-FIRE) (NUREG – 7010) Phase 1: Horizontal Trays                       | July 2012      |               | July 2012                      | RES/DRA |
| Publish Cable Heat Release, Ignition, and Spread in Tray Installations during fire. (CHRISTI-FIRE) (NUREG – 7010) Phase 2: Phase 2: Hallways and Vertical Shafts  | April 2013     |               |                                | RES/DRA |
| Issue Electric Raceway Fire Barrier System NUREG  | December 2010  |               | May 2010                       | RES/DRA |
| Conduct fourth RES/EPRI detailed fire PRA course (2 sessions)   | October 2010   |               | October 2010                   | RES/DRA |
| Issue NUREG on Fire HRA   | December 2010  | December 2011 | July 2012                      | RES/DRA |
| Publish NUREG/CR-7115 “Performance of Metal and Polymeric O-Ring Seals in Beyond-Design-Basis Temperature Excursions”   | February 2011  | April 2012    | April 2012                     | RES/DRA |
| Second phase of “Performance of Metal and Polymeric O-Ring Seals in Beyond-Design-Basis Temperature Excursion”  | November 2014  |               |                                | RES/DRA |
| Letter Report on Insights from Analyses of Events and Inspection Reports on Determining Risk Significance of Inspection Findings for Fuel Cycle Oversight Process | November 2011  | February 2012 | December 2011                  | RES/DRA |
| Conduct fifth RES/EPRI detailed fire PRA course (2 sessions)  | November 2011  |               | November 2011                  | RES/DRA |
| Conduct sixth RES/EPRI detailed fire PRA course (2 sessions)  | September 2012 |               | September 2012                 |         |
| Support NFPA 805 implementation (e.g. Unreviewed Analysis Methods)  | Ongoing        |               |                                | RES/DRA |
| Annual Metrics Methodology Report evaluating fire protection metrics on 10CFR50.72/73 reportable fires and on fire protection findings                            | April 2011     |               | April 2011<br>(Updated Yearly) | RES/DRA |